RDR TO SDR CONVERSION

VISIBLE/INFRARED IMAGER/RADIOMETER SUITE ALGORITHM THEORETICAL BASIS DOCUMENT

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

GLOSSARY OF ACRONYMS

ATB	Algorithm Theoretical Basis
ATBD	Algorithm Theoretical Basis Document
AVHRR	Advanced Very High Resolution Radiometer
DN	Digital Number
DoD	Department of Defense
EDR	Environmental Data Record
GSD	Ground Sampling Distance
HSR	Horizontal Spatial Resolution
IPO	Integrated Program Office
MODIS	Moderate Resolution Imaging Spectroradiometer
MTF	Modulation Transfer Function
NASA	National Aeronautics and Space Administration
NedL	Noise Equivalent Delta Radiance
NOAA	National Oceanic and Atmospheric Administration
NPOESS	National Polar-orbiting Operational Environmental Satellite System
NPP	NPOESS Preparatory Project
OLS	Operational Linescan System
RDR	Raw Data Record
SBRS	Santa Barbara Remote Sensing
SDR	Sensor Data Record
SNR	Signal-to-Noise Ratio
SRD	Sensor Requirements Document
TIROS	Television Infrared Observation Satellite
TOA	Top of Atmosphere
VIIRS	Visible/Infrared Imager/Radiometer Suite

ABSTRACT

The Visible/Infrared Imager/Radiometer Suite (VIIRS) is slated to fly onboard the National Polar-orbiting Operational Environmental Satellite System (NPOESS), which is scheduled for launch in the late 2000's. The requirements for the VIIRS EDRs are described in detail in the VIIRS Sensor Requirements Document (SRD). These requirements form the foundation from which both the algorithms and the sensor are designed and built. A revised version of the SRD was released in November 1999, detailing a set of new requirements targeted toward the NPOESS Preparatory Program (NPP), a National Aeronautics and Space Administration (NASA) endeavor to build upon the MODIS heritage beginning in 2005. Incremental updates to the SRD have followed, with minor changes.

Most of the VIIRS EDR algorithms will require as input radiometric data from one or more VIIRS spectral bands. These data will generally be ingested in one of three forms:

    1) Calibrated top of atmosphere (TOA) Radiances

    2) Calibrated TOA Reflectances

    3) Calibrated TOA Brightness Temperatures

This document describes the generation of three Sensor Data Records (SDRs) corresponding to the three inputs listed above. These SDRs comprise the basis for all of the VIIRS EDR retrievals. Their structure is very basic and draws heavily upon heritage for similar Level 1 products.

1.0   INTRODUCTION

1.1   PURPOSE

This algorithm theoretical basis document (ATBD) describes the algorithms used to retrieve the Calibrated top of atmosphere (TOA) Radiances Sensor Data Record (SDR), the Calibrated TOA Reflectances SDR, and the Calibrated Brightness Temperatures SDR, as the primary Level 1 product of the Visible/Infrared Imager/Radiometer Suite (VIIRS). The primary purpose of this ATBD is to establish guidelines for the production of these SDRs. This document will describe the required inputs, a theoretical and mathematical description of the algorithms, practical considerations for post-launch implementation, and the assumptions and limitations associated with the products.

1.2   SCOPE

This document covers the algorithm theoretical basis (ATB) for the operational retrieval of the Calibrated TOA Radiances SDR, the Calibrated TOA Reflectances SDR, and the Calibrated TOA Brightness Temperatures SDR. Any derived products beyond these three SDRs will not be discussed beyond brief mention. Geolocation, another part of the Raw Data Record (RDR) to SDR conversion process, is discussed in *[V-1]*.

Section 1 describes the purpose and scope of this document; it also includes a listing of VIIRS documents that will be cited in the following sections. Section 2 provides a brief overview of the motivation for the SDRs, including the objectives of the retrievals, the currently designed VIIRS instrument characteristics, and the strategy for retrieval of the SDRs. Section 3 contains the essence of this document—a complete description of the SDRs. Consideration is given to the overall structure, the required inputs, a theoretical description of the products, and practical implementation issues. Section 4 provides an overview of the constraints, assumptions and limitations associated with the SDRs, and Section 5 contains a listing of references cited throughout the course of this document.

1.3   VIIRS DOCUMENTS

Reference to VIIRS documents within this ATBD will be indicated by an italicized number in brackets, e.g., *[V-1]*.

[V-1] VIIRS Geolocation ATBD.

[V-2] VIIRS Calibration/Validation Plan.

1.4   REVISIONS

This is the first working version of this document, version 3.0. It is dated May 8, 2000. There were no versions numbered 1.0 or 2.0; the current version number has been selected to match the delivery of the previously existing VIIRS EDR ATBDs, which underwent two previous version releases.

2.0   EXPERIMENT OVERVIEW

2.1   OBJECTIVES OF SDR RETRIEVALS

One or more of the SDRs described in this document are necessary inputs to most of the VIIRS EDR algorithms. All VIIRS EDR algorithms use these data either directly or indirectly. These SDRs form the link between sensor measurements and algorithm inputs, relating collected photons at the sensor aperture to radiance fields at the top of the atmosphere, which in turn are related via the EDR algorithms to surface and/or atmospheric properties.

2.2   INSTRUMENT CHARACTERISTICS

The VIIRS instrument will now be briefly described to clarify the context of the descriptions of the SDRs presented in this document. VIIRS can be pictured as a convergence of three existing sensors, two of which have seen extensive operational use at this writing.

The Operational Linescan System (OLS) is the operational visible/infrared scanner for the Department of Defense (DoD). Its unique strengths are controlled growth in spatial resolution through rotation of the ground instantaneous field of view (GIFOV) and the existence of a low-level light sensor (LLLS) capable of detecting visible radiation at night. OLS has primarily served as a data source for manual analysis of imagery. The Advanced Very High Resolution Radiometer (AVHRR) is the operational visible/infrared sensor flown on the National Oceanic and Atmospheric Administration (NOAA) Television Infrared Observation Satellite (TIROS-N) series of satellites (Planet, 1988). Its unique strengths are low operational and production cost and the presence of five spectral channels that can be used in a wide number of combinations to produce operational and research products. In December 1999, the National Aeronautics and Space Administration (NASA) launched the Earth Observing System (EOS) morning satellite, *Terra*, which includes the Moderate Resolution Imaging Spectroradiometer (MODIS). This sensor possesses an unprecedented array of thirty-two spectral bands at resolutions ranging from 250 m to 1 km at nadir, allowing for unparalleled accuracy in a wide range of satellite-based environmental measurements.

VIIRS will reside on a platform of the National Polar-orbiting Operational Environmental Satellite System (NPOESS) series of satellites. It is intended to be the product of a convergence between DoD, NOAA and NASA in the form of a single visible/infrared sensor capable of satisfying the needs of all three communities, as well as the research community beyond. As such, VIIRS will require three key attributes: high spatial resolution with controlled growth off nadir, minimal production and operational cost, and a large number of spectral bands to satisfy the requirements for generating accurate operational and scientific products.

Figure 1 illustrates the design concept for VIIRS, designed and built by Raytheon Santa Barbara Remote Sensing (SBRS). At its heart is a rotating telescope scanning mechanism that minimizes the effects of solar impingement and scattered light. Calibration is performed onboard using a solar diffuser for short wavelengths and a V-groove blackbody source and deep space view for thermal wavelengths. A solar diffuser stability monitor (SDSM) is also included to track the performance of the solar diffuser. The nominal altitude for NPOESS will be 833 km. The VIIRS scan will extend to 56 degrees on either side of nadir.

The VIIRS Sensor Requirements Document (SRD) places explicit requirements on spatial resolution for the Imagery EDR. Specifically, the horizontal spatial resolution (HSR) of bands used to meet threshold Imagery EDR requirements must be no greater than 400 m at nadir and 800 m at the edge of the scan. This led to the development of a unique scanning approach which optimizes both spatial resolution and signal to noise ratio (SNR) across the scan. The concept is summarized in Figure 2 for the imagery bands; the nested lower resolution radiometric bands follow the same paradigm at exactly twice the size. The VIIRS detectors are rectangular, with the smaller dimension projecting along the scan. At nadir, three detector footprints are aggregated to form a single VIIRS "pixel." Moving along the scan away from nadir, the detector footprints become larger both along track and along scan, due to geometric effects and the curvature of the Earth. The effects are much larger along scan. At around 32 degrees in scan angle, the aggregation scheme is changed from 3x1 to 2x1. A similar switch from 2x1 to 1x1 aggregation occurs at 48 degrees. The VIIRS scan consequently exhibits a pixel growth factor of only 2 both along track and along scan, compared with a growth factor of 6 along scan which would be realized without the use of the aggregation scheme. Figure 3 illustrates the benefits of the aggregation scheme for spatial resolution.
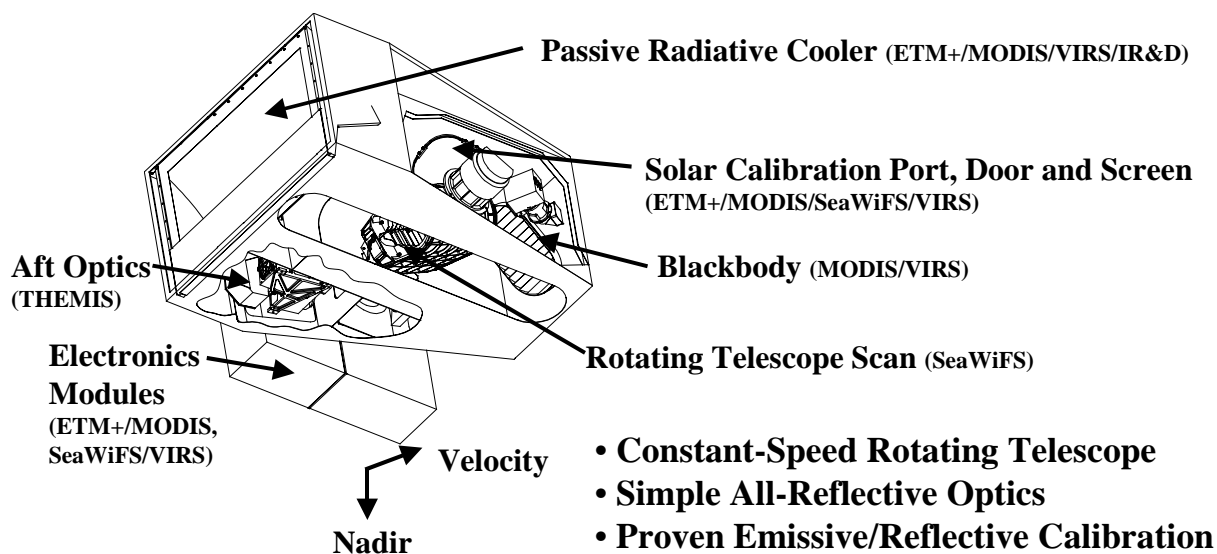

Passive Radiative Cooler (ETM+/MODIS/VIRS/IR&D)

Solar Calibration Port, Door and Screen (ETM+/MODIS/SeaWiFS/VIRS)

Blackbody (MODIS/VIRS)

Aft Optics (THEMIS)

Electronics Modules (ETM+/MODIS, SeaWiFS/VIRS)

Rotating Telescope Scan (SeaWiFS)

Velocity

Nadir

- **Constant-Speed Rotating Telescope**
- **Simple All-Reflective Optics**
- **Proven Emissive/Reflective Calibration**

Figure 1. Summary of VIIRS design concepts and heritage.

Imaging ("High-Resolution") Bands

Nadir

• aggregate 3 samples
• SNR increases by sqrt(3)

371 m

131 m

393 m

2028 km

• limit for aggregating 2 samples
• SNR increases by sqrt(2)

605 m

393 m

786 m

3000 km

• no aggregation

800 m

800 m
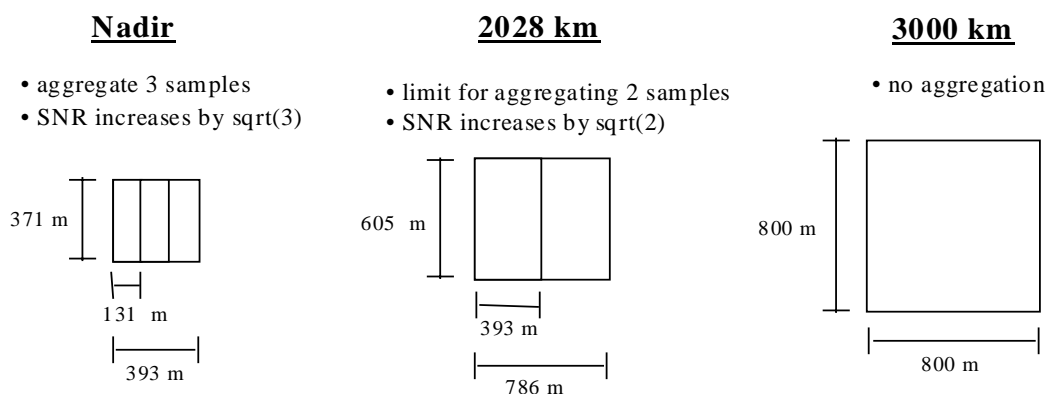
Figure 2. VIIRS detector footprint aggregation scheme for building "pixels."

Scan HSI as a Function of Scan Angle for Unit Raw GSD at Nadir

HSI Returns to Nadir size at the two transition points (31.71° and 47.87°)
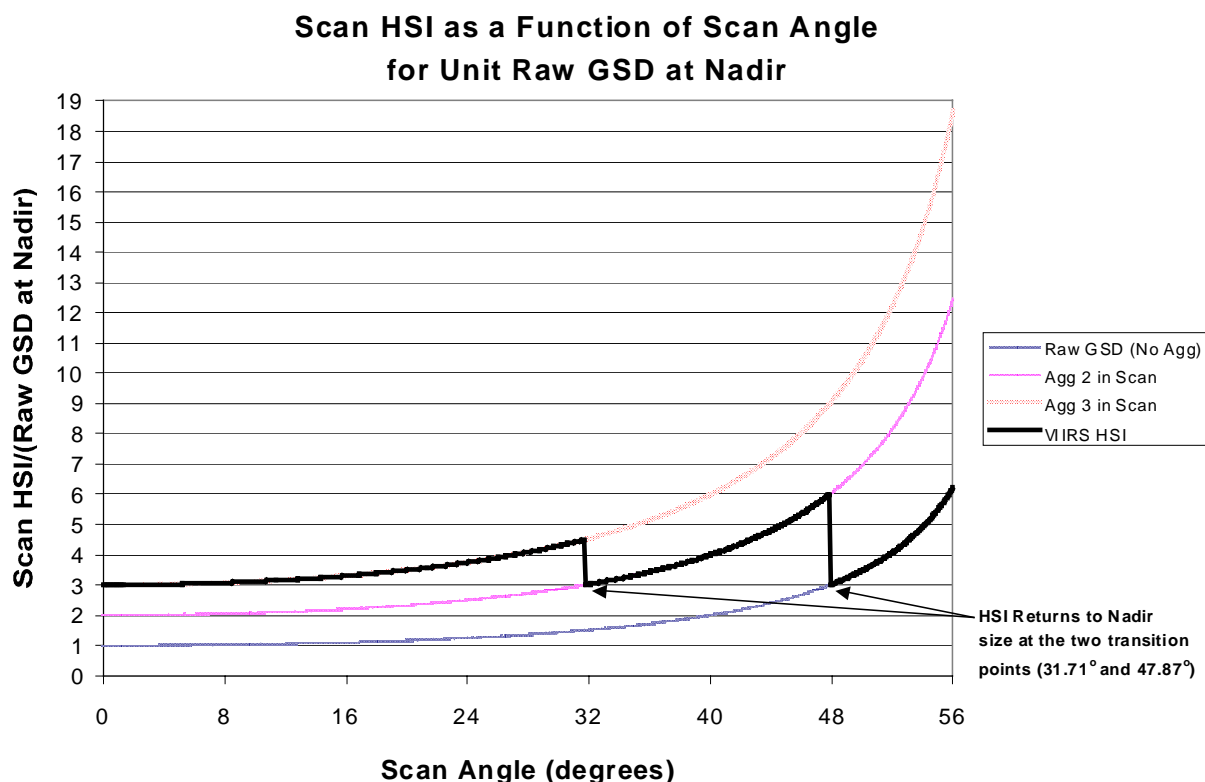
Figure 3. Benefits of VIIRS aggregation scheme in reducing pixel growth at edge of scan.

The VIIRS baseline performance is summarized in Table 1 and Table 2 for low and high radiances, respectively. The exact values of these numbers can be expected to change through the design and fabrication stages for VIIRS; each release of this document will reflect the latest numbers at the time of its release, however minor discrepancies may develop if the document is being read a significant amount of time since the most recent release. The positioning of the VIIRS spectral bands is summarized in Figure 4 through Figure 7.

Table 1. VIIRS baseline performance and specifications, low radiance range.

Table 2. VIIRS baseline performance and specifications, high radiance range.
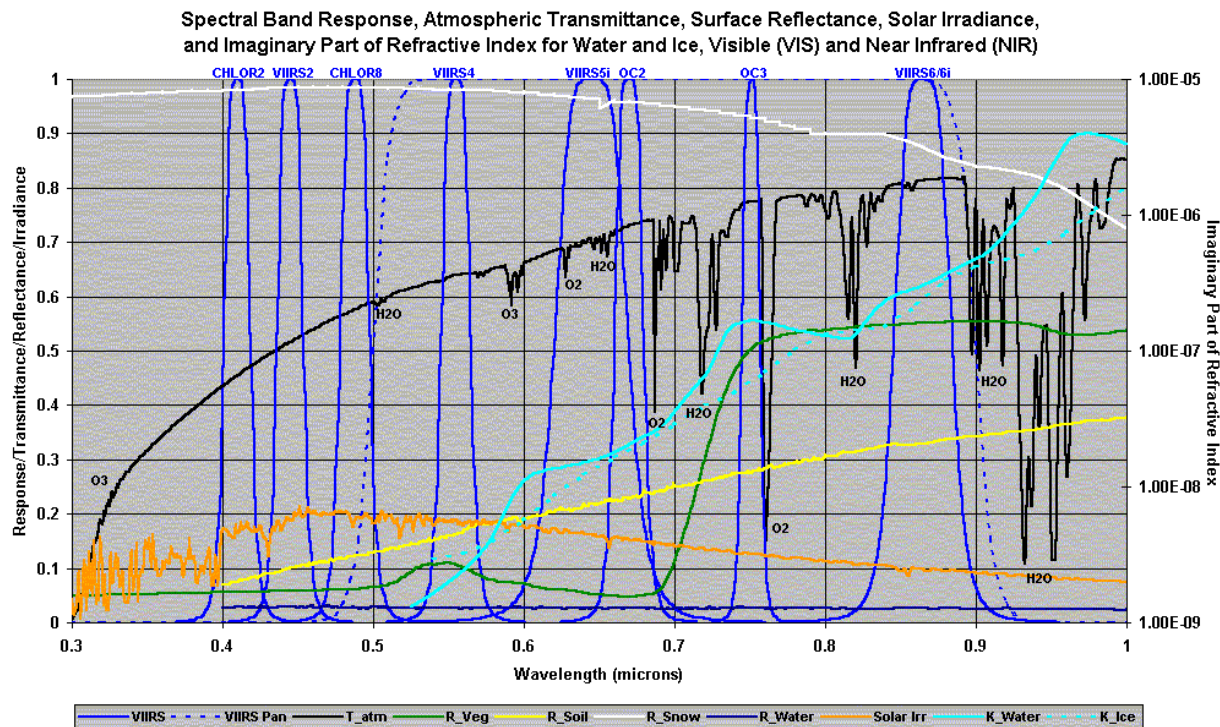
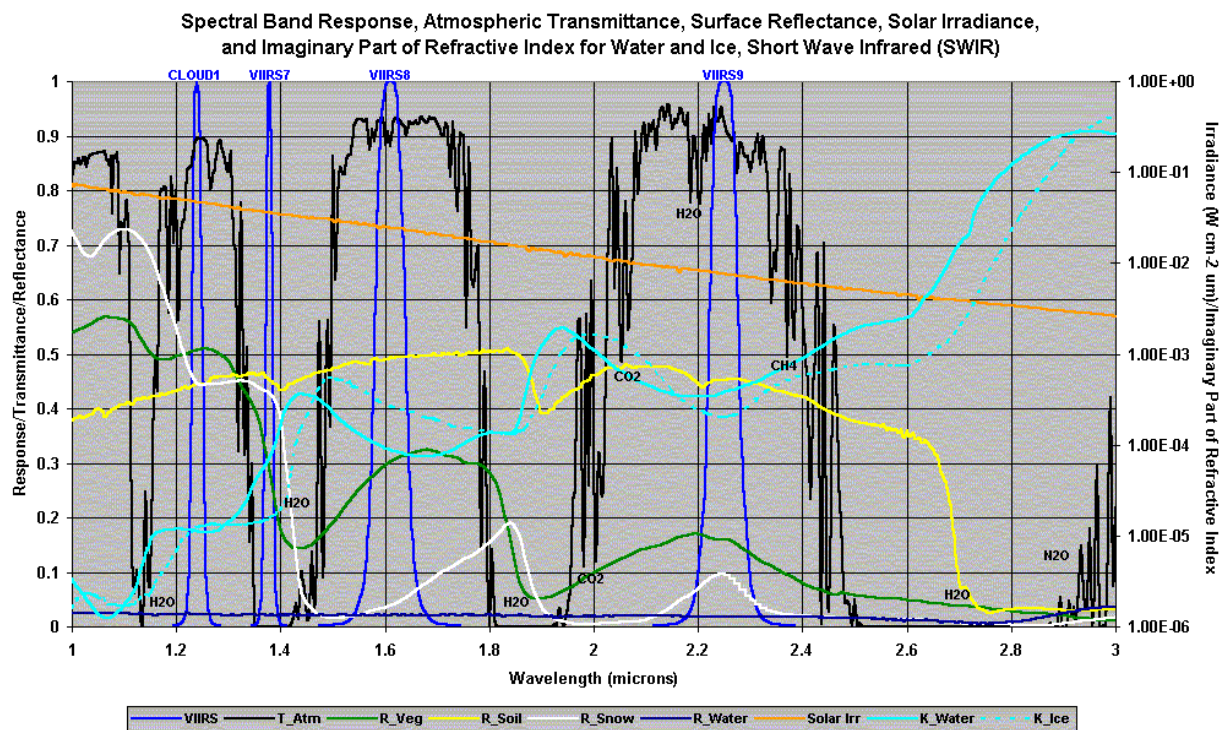**Figure 4. VIIRS spectral bands, visible and near infrared.**

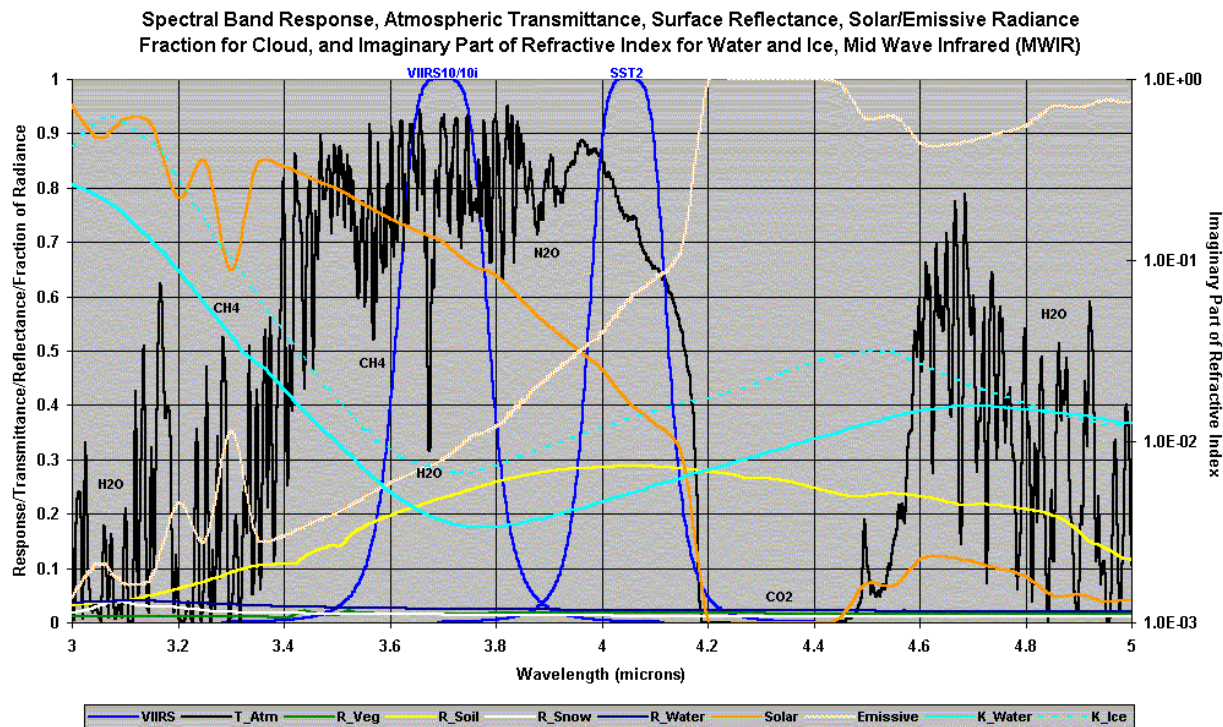**Figure 5. VIIRS spectral bands, short wave infrared.**

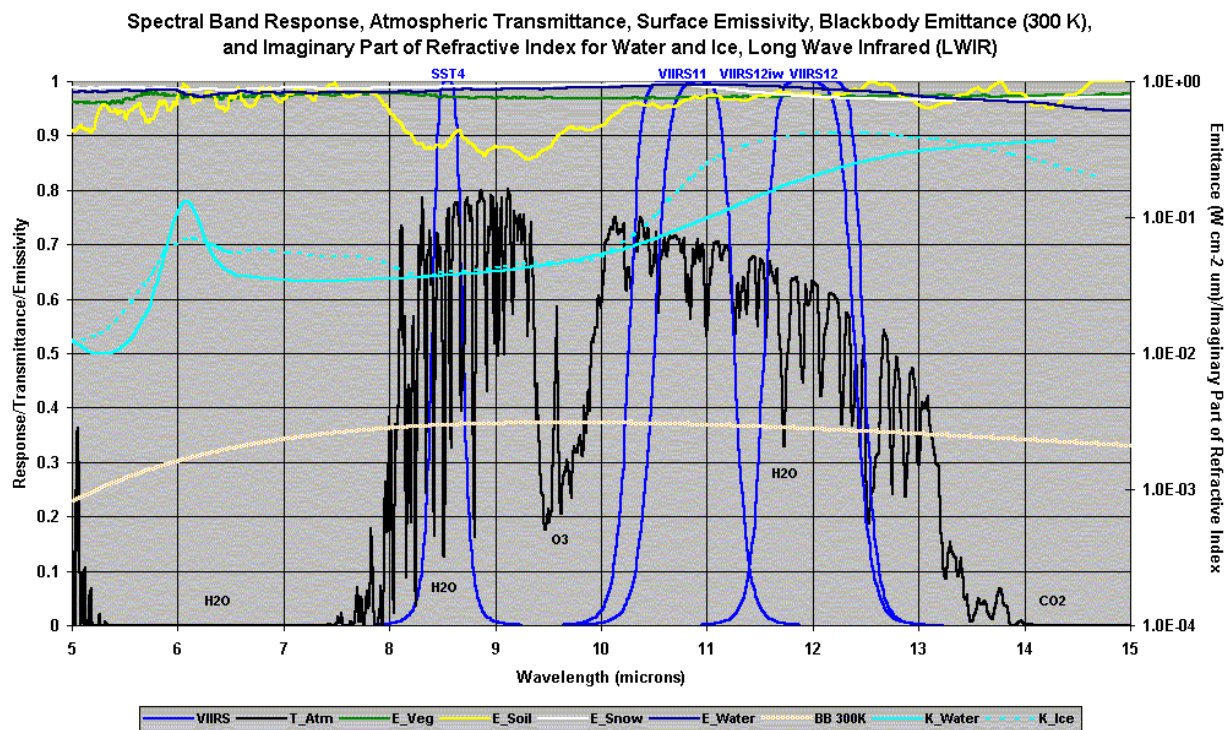**Figure 6. VIIRS spectral bands, medium wave infrared.**

Figure 7. VIIRS spectral bands, long wave infrared.

2.3   RETRIEVAL STRATEGY

The VIIRS SDRs will be generated up front in the algorithm subsystem. The Calibrated TOA Radiances SDR will be generated for all active bands at all times. The Calibrated TOA Reflectances SDR will be generated for all active reflective bands at all times. The Calibrated TOA Brightness Temperatures SDR will be generated for all active emissive bands, including three normally reflective bands, at all times. Table 3 summarizes the bands for which each product will be retrieved.

Table 3. Bands included in the three primary VIIRS SDRs.

Band	Center (μm)	Calibrated TOA Radiances SDR	Calibrated TOA Reflectances SDR	Calibrated TOA Brightness Temperatures SDR	Notes
Chlor2	0.412	X	X		
2	0.445	X	X		
Chlor8	0.488	X	X		
4	0.555	X	X		
5i	0.645	X	X		Imagery Resolution
Oc2	0.672	X	X		
Oc3	0.751	X	X		
6i	0.865	X	X		Imagery Resolution
6r	0.865	X	X		
Cloud1	1.240	X	X	X	Emissive for Fires
7	1.378	X	X		
8i	1.610	X	X		Imagery Resolution
8r	1.610	X	X	X	Emissive for Fires
9	2.250	X	X	X	Emissive for Fires
10r	3.700	X		X	
10i	3.740	X		X	Imagery Resolution
Sst2	4.050	X		X	
Sst4	8.550	X		X	
11	10.783	X		X	
12i	11.450	X		X	Imagery Resolution
12r	12.013	X		X	
DNB	0.700	X	X		Day/Night Band

3.0   ALGORITHM DESCRIPTION

3.1   PROCESSING OUTLINE

Figure 8 shows the context of the Build SDR module. Figure 9 shows more detail in the software architecture for the Build SDR module. This includes the generation of calibrated radiances, reflectances, and brightness temperatures. Geolocation is discussed in *[V-1]*. Details concerning calibration methodology are discussed in *[V-2]*.
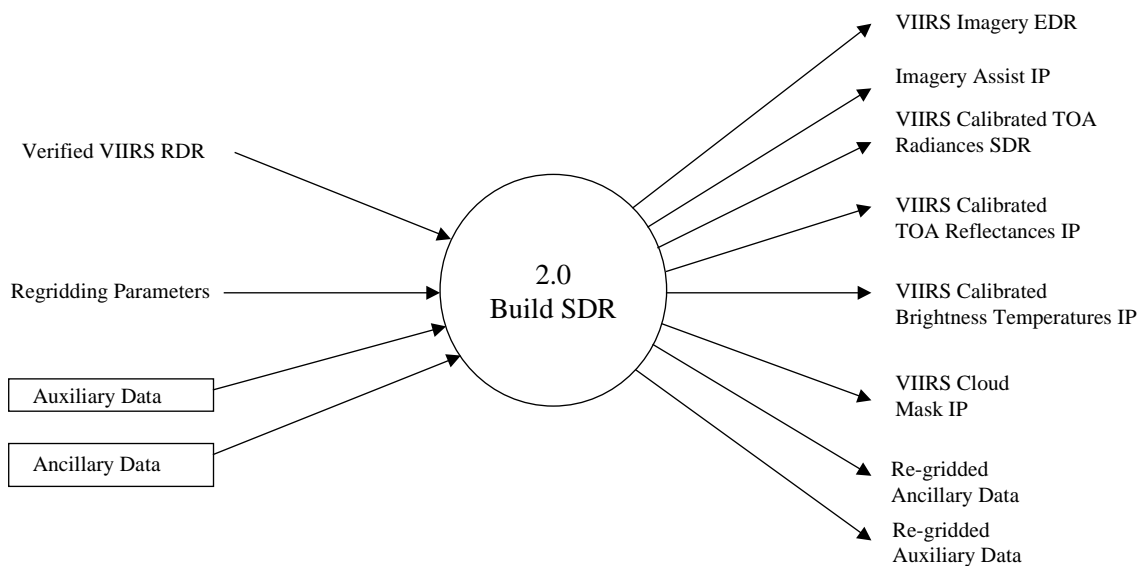
<u>Build SDRs Context Level Diagram</u>

Figure 8. Context level software architecture for the Build SDR module.

Figure 9. High level software architecture for the Build SDR module.

3.2 ALGORITHM INPUT

3.2.1 VIIRS Data

The required input for generation of the three primary VIIRS SDRs (radiances, reflectances, and brightness temperatures) is the Verified VIIRS RDR, which contains the basic digital numbers to be converted into radiance or reflectance by applying calibration coefficients. The calibration coefficients themselves are also included in the RDR, along with other elements of the telemetry.

3.2.2 Non-VIIRS Data

No non-VIIRS data are required for the generation of the primary VIIRS SDRs.

3.3 THEORETICAL DESCRIPTION OF SDR RETRIEVALS

3.3.1 Mathematical Description

3.3.1.1 Calibrated Radiances

In VIIRS bands ranging from 3.7 μm to longer wavelengths, calibrated radiances are derived by multiplying the input digital number (DN) data, per pixel, by the appropriate calibration gain, and then adding the appropriate calibration offset. The DN values, gains, and offsets are all provided in the Verified VIIRS RDR data stream.

For VIIRS bands with center wavelengths shorter than 3.7 μm, calibrated TOA reflectances are derived first from the calibration gains and offsets, and then converted to the basic radiance currency using a reverse of the process described in Section 3.3.2.2.

3.3.1.2 Calibrated TOA Reflectances

To convert radiances (R_{EV}) to reflectances (ρ_{EV}), the following equation should be used:

$$\rho_{EV} = \pi * R_{EV} / \cos(\theta_{EV}) * E_{sun} \tag{1}$$

where E_{sun} is the extraterrestrial solar irradiance in a band, π is the number pi (3.14159…), and $\cos(\theta_{EV})$ is the cosine of the solar zenith angle measured from the normal to the Earth.

3.3.1.3 Calibrated Brightness Temperatures

The blackbody radiance (R) function is

$$R = 2\,h\,\nu^3 / [c^2(\exp\{-h\nu/kT\}-1)] \tag{2}$$

where

ν is the wavenumber (cm^{-1}),

h is the Planck constant,

c is the speed of light,

k is Boltzman's constant,

and T is the temperature in Kelvin.

The above equation can be written as

$$R = c_1 \nu^3 / [c^2(\exp\{-c_2\nu/T\}-1)] \tag{3}$$

where c_1 and c_2 are two blackbody constants equal to 0.01191071 and 1.438838 respectively using cgs units.

It can be solved for the brightness temperature (T or T_b) to give:

$$T_b = c_2 \nu / \ln(1 + c_1 \nu^3 / R) \tag{4}$$

The monochromatic radiance (R) is

$$R = R_{TOA}/(bandwidth) \tag{5}$$

where R_{TOA} is the top of the atmosphere radiance given by the calibration algorithm and the bandwidth equals the difference between the upper and lower wavelengths of the band (i.e., full width at half maximum).

3.3.2   Archived Algorithm Output

The output of the processes discussed above includes three SDRs: Calibrated TOA Radiances, Calibrated TOA Reflectances, and Calibrated TOA Brightness Temperatures. These SDRs are pushed through the VIIRS pipeline to be utilized by the EDR algorithms. No long-term storage of these data beyond immediate use by the EDR algorithms is required to meet the SRD requirements. Long-term archival of the VIIRS Calibrated TOA Radiances SDR, if desired by the user community, will be discussed in a future version of this document.

3.5   PRACTICAL CONSIDERATIONS

3.5.1   Numerical Computation Considerations

Paragraph SRDV3.2.1.5.4-1 of the VIIRS SRD states the following:

> *"The scientific SDR and EDR algorithms delivered by the VIIRS contractor shall be convertible into operational code that is compatible with a 20 minute maximum processing time at either the DoD Centrals or DoD field terminals for the conversion of all pertinent RDRs into all required EDRs for the site or terminal, including those based wholly or in part on data from other sensor suites."*

RDR here stands for Raw Data Record. This essentially means that any and all EDRs must be completely processed from VIIRS raw data, including calibration and georeferencing within 20 minutes from the time the raw data are available. This requirement is a strong reminder that VIIRS is an operational instrument.

The calculations used to derive Calibrated TOA Radiances, Calibrated TOA Reflectances, and Calibrated TOA Brightness Temperatures are straightforward and leave a minimum impact on VIIRS processing resources.

3.5.2   Programming and Procedural Considerations

The software for the Build SDR module is discussed in the VIIRS Algorithm Subsystem Specification document.

4.0 REFERENCES

IPO (2000). Visible/Infrared Imager/Radiometer Suite (VIIRS) Sensor Requirements Document (SRD) for National Polar-Orbiting Operational Environmental Satellite System (NPOESS) spacecraft and sensors, Rev. 2b/c. Prepared by Assoc. Directorate for Acquisition, NPOESS Integrated Program Office, Silver Spring, MD.

Planet, W.G. (ed.), (1988). Data extraction and calibration of TIROS-N/NOAA radiometers. NOAA Technical Memorandum NESS 107 – Rev. 1, Oct. 1988. 130 pp.